

**IN THE UNITED STATES DISTRICT COURT  
FOR THE WESTERN DISTRICT OF TEXAS  
MIDLAND/ODESA DIVISION**

COBBLESTONE WIRELESS, LLC,

Plaintiff,

v.

APPLE INC.,

Defendant.

Civil Action No. 7:24-cv-00232-ADA

**Jury Trial Demanded**

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**DECLARATION OF DR. BERTRAND HOCHWALD PH.D. IN SUPPORT OF  
APPLE'S CLAIM CONSTRUCTIONS FOR  
TERMS IN U.S. PATENT NOS. 7,924,802 AND 8,891,347**

**TABLE OF CONTENTS**

I. INTRODUCTION ..... 1

II. QUALIFICATIONS AND PROFESSIONAL EXPERIENCE..... 2

III. COMPENSATION ..... 4

IV. TOPICS CONSIDERED ..... 4

V. MATERIALS CONSIDERED IN FORMING MY OPINIONS ..... 5

VI. CLAIM CONSTRUCTION PRINCIPLES ..... 5

VII. THE '802 PATENT ..... 7

    A. LEVEL OF ORDINARY SKILL IN THE ART IN THE '802 PATENT..... 7

    B. TECHNICAL BACKGROUND OF THE '802 PATENT ..... 8

    C. THE '802 PATENT DISPUTED CLAIM TERMS..... 12

        1. “[first/second] center frequency” (claims 1–2, 10)..... 12

VIII. THE '347 PATENT ..... 13

    A. LEVEL OF ORDINARY SKILL IN THE ART IN THE '347 PATENT..... 13

    B. TECHNICAL BACKGROUND OF THE '347 PATENT ..... 14

    C. THE '347 PATENT DISPUTED CLAIM TERMS..... 17

        1. “predistorted” (claim 19) ..... 17

        2. “path parameter information” (claims 19–22) ..... 21

I, Bertrand Hochwald, Ph.D., hereby declare:

## **I. INTRODUCTION**

1. I have been retained by Ropes & Gray LLP on behalf of Defendant Apple Inc. (“Apple”) in the above matter adverse to Plaintiff Cobblestone Wireless, LLC (“Cobblestone”). I am submitting this Declaration to address the meaning and construction of certain disputed terms in U.S Patent No. 7,924,802 (“’802 Patent”) and U.S Patent No. 8,891,347 (“’347 Patent”). For the purposes of this Declaration, I have not been asked to opine on the meaning of any other disputed term not addressed below.

2. In forming my opinions, I understand that the claims should be interpreted as they would be understood by a person of ordinary skill in the art of the patent at the time its application was filed. I understand that the claims are to be construed with reference to the patent’s specification, the claims, the prosecution history, in light of the plain meaning of the terms used in the claims, and with reference to other sources of information, such as dictionaries, textbooks, and literature or other patents in the same or related fields.

3. My opinions are based on my years of education, research and experience, as well as my investigation and study of relevant materials, including those identified in this Declaration.

4. I may rely upon these materials, my knowledge and experience, and/or additional materials in forming any necessary opinions. Further, I may also consider additional documents and information to rebut arguments raised by the Plaintiff. I reserve any right that I may have to supplement this Declaration if further information becomes available or if I am asked to consider additional information. Furthermore, I reserve any right that I may have to consider and comment on any additional expert statements or testimony of Plaintiff’s expert(s) in this matter.

5. My analysis of the materials produced in this investigation is ongoing and I will continue to review any new material as it is provided. This Declaration represents only those opinions I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

## **II. QUALIFICATIONS AND PROFESSIONAL EXPERIENCE**

6. I am an expert in the field of wireless telecommunication systems, and have over twenty nine years of combined industry and academic experience in the research and design of systems for signal processing, and wireless and wireline communications. I have summarized my educational background, work experience, and other relevant qualifications in this section. Attached hereto as Appendix A, is a true and correct copy of my curriculum vitae describing my background and experience.

7. In 1995, I received a Ph.D. in Electrical Engineering from Yale University. My Ph.D. work involved the analysis and processing of electromagnetic and audio signals for the estimation of the location of electromagnetic and audio sources. In 1993, I received an M.A. in Statistics from Yale University. My primary area of study was Statistical Signal Processing. I received an M.S. in Electrical Engineering from Duke University in 1986, and a B.S. in Engineering from Swarthmore College in 1984.

8. My most recent appointment, starting in 2011, is with the University of Notre Dame, where I am currently a Freimann Chaired Professor of Electrical Engineering. I teach both graduate and undergraduate classes in Communication Systems and in Signals and Systems, where the emphasis is on the processing of analog and digital signals. My primary areas of research include communication systems, multi-antenna multi-user

systems, radio-frequency circuits, and signal design and processing. I advise graduate students who are attaining Ph.D. degrees through research and coursework.

9. Prior to Notre Dame, I worked from 2005-2010 at Beceem Communications, a cellular wireless communication chipset start-up company in Santa Clara, California, where I was Chief Scientist and Vice President of Systems Engineering. I was an integral part of the chipset development team. Beceem was bought by Broadcom Corporation in 2010 and no longer exists as a separate company.

10. Prior to Beceem, I worked from 1996-2005 at Lucent Bell Laboratories in New Jersey, where I was as a Distinguished Member of the Technical Staff doing research into communications systems and multiple-antenna systems. As a result of my research, I obtained many patents and wrote numerous publications across a variety of areas in communication theory, information theory, and circuit design.

11. Prior to Bell Laboratories, I was a Visiting Assistant Professor at the University of Illinois in Urbana-Champaign during the 1995-1996 school year, where I worked on a broad range of research topics related to signal processing and communications.

12. Prior to completing my Ph.D., during 1986-1989 I worked at the Department of Defense as a system engineer for signal processing and wireless communication systems. In this job I designed communication equipment for a variety of wireless systems.

13. I have published approximately 110 articles in scholarly conferences and journals, many of them within the journals of the Institute of Electrical and Electronic Engineers (IEEE), one of the premier societies for electrical engineers. I have been an

invited and plenary speaker at several international conferences throughout the world and have received awards and recognition for my research and publications.

14. I have 55 granted patents in a variety of areas related to communication and signal processing systems. I have had experience drafting and successfully prosecuting my own patents, and have worked with other experts in signal processing systems as a co-inventor and co-author.

15. Since 2012, I have engaged in consulting work as an expert in various litigation matters including acoustic echo cancelling, multi-antenna technologies, cellular and wireless local-area-net standards and technologies, and touch-screen technologies. I have served as an expert on behalf of both plaintiffs and defendants in patent cases. I have served as a technology expert in various aspects of the litigation process, including trade secret disputes, trial testimony, Markman hearings, and *inter partes* reviews.

### **III. COMPENSATION**

16. I am being compensated for my time at my rate of \$790 per hour. I am being reimbursed for reasonable and customary expenses associated with my work. My compensation is not dependent on the results of my work, the substance of my opinions, or the outcome of any proceeding involving the asserted claims. I have no financial interest in the outcome of this matter.

### **IV. TOPICS CONSIDERED**

17. I have been asked to opine on the meaning and construction of the disputed terms discussed below. I have not been asked to opine on the meaning or construction of any other disputed term other than those discussed below. I have also been asked to provide general background information regarding the technology, as set forth below.

18. I have been asked to provide an opinion on the following terms of the '802 Patent and the '347 Patent:

<b>'802 Claim Terms</b>
[first/second] center frequency (claims 1–2, 10)
<b>'347 Claim Terms</b>
path parameter information (claims 19–22)
predistorted (claim 19)

## V. MATERIALS CONSIDERED IN FORMING MY OPINIONS

19. In preparing my opinions, I have reviewed the '802 and the '347 Patents, and their prosecution histories, and I have also reviewed the other documents and materials cited herein. Each of these materials is a type of document that experts in my field would reasonably rely upon when forming their opinions in a matter such as this one.

20. My opinions are also based upon my education, training, research, knowledge, and personal and professional experience.

## VI. CLAIM CONSTRUCTION PRINCIPLES

21. I am not an attorney or a patent attorney, and offer no opinions on the law. I have, however, been informed by counsel regarding various legal standards that may apply to this case, and I have applied those standards where necessary in arriving at my conclusions.

22. I understand that patent claims are construed from the viewpoint of a person of ordinary skill in the art ("POSITA") of the patent at the time of the invention. I have been told that patent claims generally should be interpreted consistent with their plain and ordinary meaning as understood by a POSITA in the relevant time period (*i.e.*, at the time

of the invention, or the so called “effective filing date” of the patent application), after reviewing the patent claim language, the specification and the prosecution history (*i.e.*, the intrinsic record).

23. I further understand that a POSITA must read the claim terms in the context of the claim itself, as well as in the context of the entire patent specification. I understand that in the specification and prosecution history, the patentee may specifically define a claim term in a way that differs from the plain and ordinary meaning. I understand that the prosecution history of the patent is a record of the proceedings before the U.S. Patent and Trademark Office, and may contain explicit representations or definitions made during prosecution that affect the scope of the patent claims. I understand that an applicant may, during the course of prosecuting the patent application, limit the scope of the claims to overcome prior art or to overcome an examiner’s rejection, by clearly and unambiguously arguing to overcome or distinguish a prior art reference, or to clearly and unambiguously disavow claim coverage. I understand that this is known as a disclaimer. Similarly, I understand that the applicant may also disclaim the scope of a claim by distinguishing a feature from other approaches in the specification.

24. In interpreting the meaning of the claim language, I understand that a POSITA may also consider “extrinsic” evidence, including expert testimony, inventor testimony, dictionaries, technical treatises, other patents, and scholarly publications. I understand this evidence is considered to ensure that a claim is construed in a way that is consistent with the understanding of those of skill in the art at the time of the claimed invention. This can be useful for technical terms whose meaning may differ from its ordinary English meaning. I understand that extrinsic evidence may not be relied on if it

contradicts or varies the meaning of claim language provided by the intrinsic evidence, particularly if the applicant has explicitly defined a term in the intrinsic record.

25. I reserve the right to respond to any additional arguments or opinions raised by Defendants' or Defendants' expert(s). I further reserve the right to respond to any new positions raised by Defendants or respond to any further expert declaration provided by Defendants regarding claim construction issues.

## **VII. THE '802 PATENT**

### **A. LEVEL OF ORDINARY SKILL IN THE ART IN THE '802 PATENT**

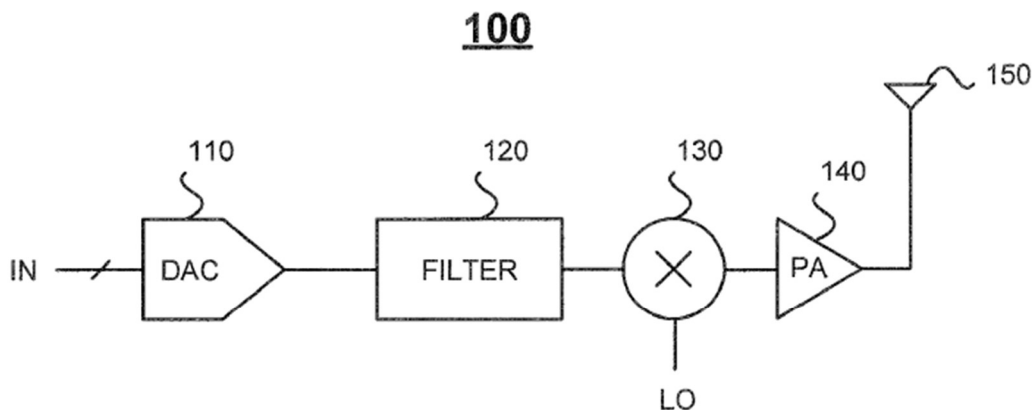
26. I understand there is a concept in patent law known as a POSITA. I understand that this concept refers to a person who is trained in the relevant technical field of a patent without possessing extraordinary or otherwise exceptional skill. I further understand that factors such as the education level of those working in the field, the sophistication of the technology, the types of problems encountered in the art, prior art solutions to those problems, and the speed at which innovations are made may help establish the level of skill in the art.

27. Taking these factors into consideration, a POSITA at the time of the '802 Patent would have had a bachelor's degree in electrical engineering, computer engineering, computer science, or a related field, and two to three years of experience in the design or development of wireless telecommunication systems, or the equivalent. Additional graduate education could substitute for professional experience, or significant experience in the field could substitute for formal education.

28. Based at least on my educational and work experience, it is my opinion that I qualify as a POSITA as of the effective filing date of the '802 Patent on January 23, 2008. My opinions herein are from the perspective of a POSITA as of that date.

**B. TECHNICAL BACKGROUND OF THE '802 PATENT**

29. The '802 patent is directed to methods for wirelessly transmitting information and purports to address the “limited . . . amount of data” that prior art wireless transmitters can transmit. '802 patent, 1:29–35. The '802 patent explains that prior art wireless communication systems “generally contain one or more transmission channels to transmit data from the transmitter to the receiver.” '802 patent, 1:12–14. The example prior art transmitter 100, shown in Figure 1 below, illustrates a single signal path from a data signal source to transmit antenna 150. '802 patent, Fig. 1, 1:17–29. In the path, “a digital-to-analog converter ('DAC') 110 receives a digital input signal” from the data source and “converts a digital signal to an analog signal.” '802 patent, 1:18–24. Next, a filter 120, coupled to the DAC output, is “used to remove undesirable frequencies and signal images.” '802 patent, 1:18–24. A mixer 130, coupled to the filter 120 output, is “used to up-convert the frequency of the signal by combining it with a local oscillator signal.” '802 patent, 1:24–29. Power amplifier 140 receives the mixer 30 output and in turn will “amplify the signal for transmission before it is sent through antenna 150.” '802 patent, 1:24–29.



**Fig. 1**  
**(prior art)**

'802 patent, Fig. 1.

30. The '802 patent purports to improve transmission capacity by “transmit[ting] multiple signals simultaneously over a communication channel at different center frequencies.” '802 patent, 6:57–64, 1:34–40. In the prior art arrangement where there is one signal path from the data signal source to the mixer, the transmitter is limited to “one center frequency (or modulation frequency).” '802 patent, 1:29–35, Fig. 1. But the “amount of information transmitted around the center frequency is limited by the bandwidth of the transmitter around the center frequency.” '802 patent, 1:32–35. The '802 specification describes a wireless transmitter with two signal paths, shown in Figure 2, that correspond to the paths that two data signals from the data source take before simultaneous transmission from antenna 209. '802 patent, 5:54–62, 6:60–63. Figure 3 provides “an example of the frequency content of the transmitted signal 300” resulting from the two signal paths. '802 patent, 5:58–60. Signal 300 is transmitted over two frequency ranges (ranges 305 with center frequency  $f_1$  (303) and 306 with center frequency  $f_2$  (304)) corresponding to each signal path. '802 patent, 6:28–34, 6:42–48.

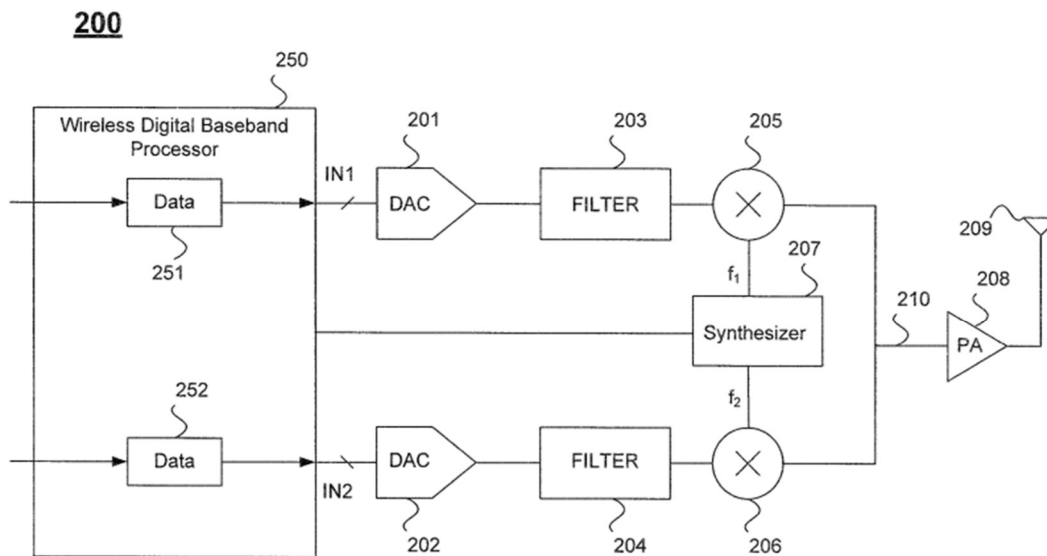


Fig. 2

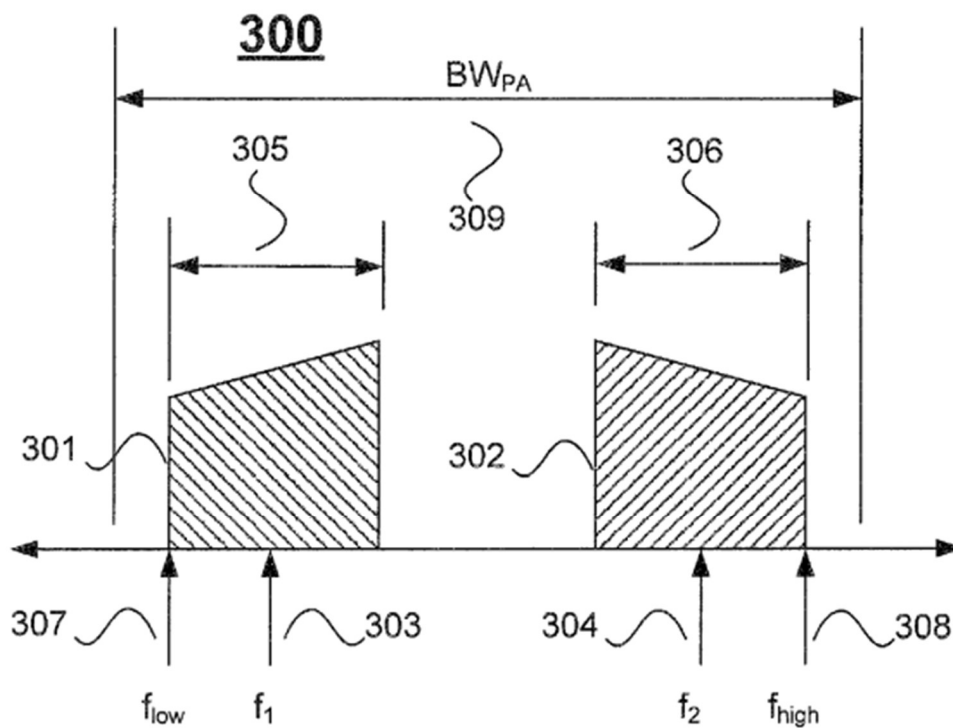


Fig. 3

'802 patent, Figs. 2–3.

31. The '802 specification identifies baseband processor 250 as the data source that provides the data to be transmitted from the wireless transmitter. '802 patent, 5:60–66 (“Information (i.e., data) to be transmitted may be received in a baseband digital system 250, such as a wireless digital baseband processor. The baseband digital system 250 provides a first digital signal that comprises first digital data 251 to be transmitted . . . and provides a second digital signal that comprises second digital data 252 to be transmitted.”). Data in digital processing systems is typically represented in a baseband signal, that is, a low-frequency signal. Digital processing techniques are generally designed to handle baseband signals because they are more easily manipulable and require less bandwidth for processing than higher frequency signals.

32. However, wirelessly transmitting a baseband signal is not practical. For one, baseband signals are not matched to the physical and regulatory specifications of wireless transmission channels. Regulatory specifications and wireless communication standards prescribe frequencies in the radio frequency (RF) range for transmission. RF frequencies are higher than baseband frequencies. Also, transmitting a baseband signal would require a large antenna, an impracticable feature for compact wireless devices. Frequency and wavelength are inversely proportional such that the baseband's low frequency means that baseband signals have a long wavelength.

33. To transmit the data wirelessly, wireless transmitters embed the data into an RF carrier signal using a process called modulation. Modulation is the process of taking a signal at the desired frequency and modulating one of its parameters (*e.g.*, amplitude, frequency, or phase) so that it carries the information to be transmitted. The '802 patent refers to this process as “up-conversion” and summarizes the process, which occurs at the

mixer element, by explaining that the data signal is “combin[ed] with a local oscillator signal (‘LO’)” at the desired frequency. ’802 patent, 1:24–27. To form the transmit RF signal, the mixer element thus combines the data signal with a carrier signal at the desired RF frequency. ’802 patent, 6:22–28, 6:35–42. This process can be done by directly mixing a baseband signal with a local oscillator signal to upconvert the baseband signal to an RF carrier signal. Alternatively, a baseband signal can first be upconverted to an intermediate frequency between the baseband frequency and the radio frequency. Subsequently, the intermediate frequency signal is upconverted to an RF signal, which is then wirelessly transmitted to a receiver. The ’802 patent describes both of these approaches. ’802 patent, 8:19–22, 8:56–61.

### C. THE ’802 PATENT DISPUTED CLAIM TERMS

#### 1. “[first/second] center frequency” (claims 1–2, 10)

Term	Cobblestone’s Proposed Construction	Apple’s Proposed Construction
“[first/second] center frequency” (claims 1–2, 10)	“the frequency of the carrier that the baseband signal is upconverted to”	Plain and ordinary meaning

34. I understand that the parties dispute the scope of the term “center frequency.” In particular, my understanding is that the primary dispute is whether the term “center frequency” is limited to “the frequency of the carrier that the baseband signal is upconverted to.” In my opinion, the term “center frequency” is a straightforward term that would be understood by a POSITA to refer to the middle frequency in a frequency range. I understand that the Federal Communications Commission defines the term “center frequency” to be “[t]he frequency of the middle of the bandwidth of a channel.” 47 C.F.R.

§ 22.99. This is consistent with how a POSITA would understand the term “center frequency.”

35. I have reviewed the ’802 patent and its file history, and nothing in these documents suggest that the term “center frequency” should be limited to “the frequency of the carrier that the baseband signal is upconverted to.” The ’802 patent and its file history never define the term “center frequency,” and do not disclaim the term to exclude anything other than the center frequency that the baseband signal is upconverted to. In fact, the term “baseband signal” is not used in the claims, the ’802 patent or its file history. Consistent with this, the claim language itself supports plain and ordinary meaning. Claim 1 states “the first frequency range having a **first center frequency**, a first highest frequency and a first lowest frequency . . . .” (emphasis added). From this, a POSITA would understand the center frequency to be in relation to the highest and lowest frequencies, neither of which are part of the proposed construction. The proposed construction including the term “frequency of the carrier” does not add clarity or remove ambiguity.

36. As such, it is my opinion that the term “center frequency” has a plain meaning that would be understood to a POSITA, and that Cobblestone’s proposed construction is inconsistent with the specification of the ’802 patent and the file history of the ’802 patent.

## VIII. THE ’347 PATENT

### A. LEVEL OF ORDINARY SKILL IN THE ART IN THE ’347 PATENT

37. As I note above, I understand there is a concept in patent law known as a POSITA. I understand that this concept refers to a person who is trained in the relevant technical field of a patent without possessing extraordinary or otherwise exceptional skill.

I further understand that factors such as the education level of those working in the field, the sophistication of the technology, the types of problems encountered in the art, prior art solutions to those problems, and the speed at which innovations are made may help establish the level of skill in the art.

38. Taking these factors into consideration, a POSITA at the time of the '347 Patent would have had a bachelor's degree in electrical engineering, computer engineering, computer science, or a related field, and two to three years of experience in the design or development of wireless telecommunication systems, or the equivalent. Additional graduate education could substitute for professional experience, or significant experience in the field could substitute for formal education.

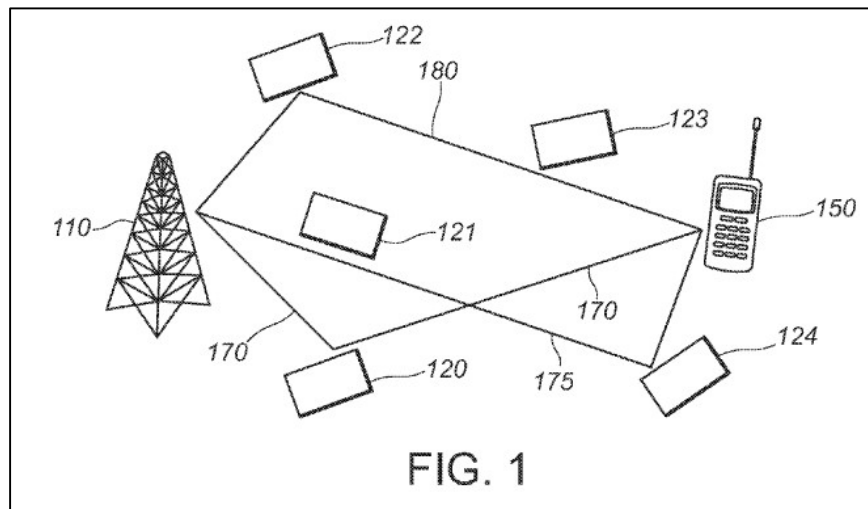
39. Based at least on my educational and work experience, it is my opinion that I qualify as a POSITA as of the effective filing date of the '347 Patent on July 28, 2011. My opinions herein are from the perspective of a POSITA as of that date.

#### **B. TECHNICAL BACKGROUND OF THE '347 PATENT**

40. The '347 patent generally relates to techniques for performing wireless communications in a communication system between a transmitter and a receiver. *See* '347, 1:45-62. According to the '347 patent, conventional systems sometimes used "equalization" techniques at the receiver in order to "recover the original transmitted signal by removing any distortions that arise in the transmittal." '347, 1:22-29. Other types of known methods for more reliably transmitting signals included "[j]oint-[p]rocessing," "[p]recoding," "spatial division multiplexing access," "[m]ultipath-[b]ased [c]hannel [s]imulation," and "[p]re-[e]qualization" techniques. '347, 10:54-12:53. By comparison, the '347 patent describes a technique for creating signals that are "pre-distorted" by artificially adding "pseudo 'distortion' before the signal are transmitted." '347, 7:63-8:3.

Doing so helps to cancel out the natural distortion that arise as the signal propagates from the transmitter to the receiver. *See* '347, 7:63-8:3. For example, by appropriately pre-distorting the signals “the pre-distortion can be removed automatically by the propagation channel, i.e. the channel itself works as an equalizer,” thus removing the need for equalization to be performed by the receiving device. '347, 9:49-58, 11:3-12.

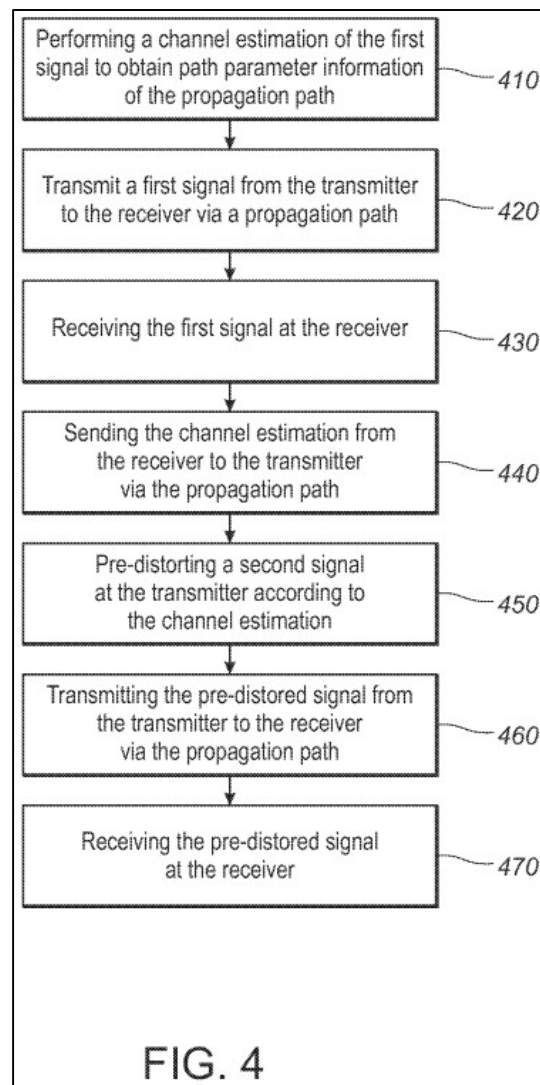
41. Figure 1 of the '347 patent shows a schematic representation of a wireless communication system, including a transmitter, a receiver, and multiple propagation paths between the two. '347, 3:20-30, Fig. 1. In general, transmitted signals may travel between the transmitter and the receiver along any of the different propagation paths. '347, 7:38-49. According to the '347 patent, these different propagation paths are due to reflections, diffraction, signal scattering, or physical obstructions that interact with signals as they propagate. *See* '347, 3:20-30, 7:38-44.



42. According to the '347 patent, each of the different propagation paths will have its own associated delay, direction of arrival, direction of departure, and Doppler frequency shift. '347, 3:47-48. As a result, the signals transmitted over different propagation paths will be distorted in different ways. '347, 3:48-50, 7:44-49. This can

cause issues when trying to recover the transmitted signals, as the different versions of the signal transmitted over the different propagation paths may add up “destructively or constructively” at the receiver. ’347, 3:48-50, 7:44-49.

43. The ’347 patent purports to address these issues by creating artificially “pre-distorted” signals that counteract the natural distortions in the propagation paths, meaning that the signal distortion is effectively “removed while propagating.” See ’347, 3:26-30, 7:38-44. For example, Figure 4 of the ’347 patent shows the steps of generating and transmitting pre-distorted signals as disclosed by the ’347 patent. ’347, Fig. 4.



44. Specifically, as described in the '347 patent, the process generally involves the steps of: (1) transmitting a first signal to a receiver along a propagation path; (2) performing channel estimation on the first signal in order to obtain path parameter information—such as “the delay  $\tau$ , the Doppler frequency  $u$ , direction of arrival  $\Omega_1$ , direction of departure  $\Omega_2$ , and complex amplitude  $\alpha$  for each of the propagation paths;” (3) sending the path parameter information back to the transmitter; (4) using the transmitter to predistort a second signal based on the path parameter information, (5) sending the predistorted second signal to the receiver, and (6) receiving the “predistorted” second signal at the receiver. '347, 8:7-9:14.

### C. THE '347 PATENT DISPUTED CLAIM TERMS

#### 1. “predistorted” (claim 19)

Term	Cobblestone’s Proposed Construction	Apple’s Proposed Construction
“predistorted” (claim 19)	Plain and ordinary meaning, “which excludes distortion after transmission”	“distorted before transmission, not including precoding using a codebook”

45. I understand that the parties dispute (1) whether “predistorted” should be defined based on what happens before transmission or after transmission, and (2) whether the '347 specification has excluded “precoding using a codebook” from the meaning of “predistorted.” As explained below, in my opinion, Apple correctly focusses on what happens before transmission. Moreover, in my opinion Apple is correct that the term “predistorted” does not include precoding using a codebook. Rather, the intrinsic record supports Apple’s construction that the term “predistorted” refers to signals that are “distorted before transmission, not including precoding using a codebook.”

46. In my opinion, the term “predistorted” means a signal that has been “distorted before transmission.” Without the disclaimers in the ’347 patent specification explicitly excluding certain subject matter from the scope of the claims, a POSITA would understand that the term “predistorted” refers to signals that are distorted before transmission. This is clear from the ’347 patent itself, which states that, “unlike the equalization technique which corrects the distortion at the receiver 150 after receiving the signals,” the new technique disclosed by the ’347 patent “adds pseudo ‘distortion’ *before* the signals are transmitted at the transmitter 100.” ’347, 7:63-8:3. The ’347 patent goes on to state that “[t]hese ‘pre-distorted’ signals are *then* transmitted in such a way that the signal distortion can be successfully removed while propagating.” ’347, 7:63-8:3; *see also id.* at 1:58-61, 2:6-10, 22-25 (disclosing that signals are distorted before they are transmitted). The patent does not specify what happens after transmission. This is consistent with the fact that “pre” refers to something that happens before, and not what happens after.

47. That understanding is also consistent with the overall approach for transmitting signals described by the ’347 patent. As discussed above in Section VIII.B (Technical Background of the ’347 Patent), the approach described by the ’347 patent includes the step of transmitting a first signal from the receiver to the transmitter, and then performing channel estimation on the received signal to determine “path parameter information,” such as estimates of “the delay  $\tau$ , the Doppler frequency  $u$ , direction of arrival  $\Omega_1$ , [or] direction of departure  $\Omega_2$ ” for the propagation paths. *See* ’347, 8:4-16, Fig. 4. The receiver then feeds back the “path parameter information to the transmitter,” which will use that path parameter information to “predistort[]” a second signal before it is sent to the

receiver. *See* '347, 9:1-14. As explained by the '347, by adding in the distortion before transmission, “the pre-distortion can be removed automatically by the propagation channel, i.e. the channel itself works as an equalizer,” thus cancelling out the distortion in the propagation channel and removing the need for traditional equalization techniques. '347, 9:49-58. According to the '347 patent, this enables the described system to use less overall transmission power, reduce interference, and simplify the design of the transmitter and receiver relative to systems that using precoding techniques. *See* '347, 3:58-67, 14:21-24.

48. In addition to providing an explanation of what “predistorted” signals include, the '347 patent also goes further to explain how “predistorted” signals differ from conventional signal processing and wireless transmission techniques. The conventional techniques that the '347 patent explicitly distinguishes and excludes “[j]oint-[p]rocessing” techniques ('347, 10:54-58); “[p]recoding techniques” ('347, 10:59-12:6); “SDMA (spatial division multiplexing access)” techniques ('347, 12:7-19); “[m]ultipath-[b]ased [c]hannel [s]imulation” techniques ('347, 12:20-31); and “[p]re-[e]qualization” techniques ('347, 12:32-53).

49. The comparison drawn in the '347 patent between *predistortion* techniques and *precoding* techniques is particularly relevant to the present claim construction dispute. Under the header “**Comparison to Precoding Techniques**,” the '347 specification explains that all of the “systems and methods described herein” make use of “predistortion” techniques, rather than the sort of “conventional precoding techniques” that use a “codebook.” Specifically, the patent states:

B. Comparison to Precoding Techniques

The systems and methods described herein can make use of *the concept of “pre-distortion,” which has significant difference from the conventional precoding techniques. The latter can make use of simplified representations of [the] channel, e.g. in terms of code-book, while the*

*system and methods described above make use of the parameters of the propagation channel, e.g. the delay, Doppler frequencies, directions of departure and directions of arrival. This full-dimensional parametric description of the channel can be much more accurate than using the codebooks.*

'347, 11:59-67. Elsewhere, the '347 patent further explains the advantages of the described approach over precoding techniques, noting that: “[t]he interference cancellation is much more efficient by using the user-focusing [i.e., the predistortion-based systems and methods of the '347 patent] than the conventional methods relying on e.g. the precoding techniques.” *Id.* at 14:21-24. In this regard, the patent describes the techniques of its invention as “user-focusing techniques.” For example, the title of the '347 patent is “User-Focusing Technique for Wireless Communication Systems.” Moreover, each of the figures illustrating embodiments of the invention are described as illustrating a “user-focusing technique.” *Id.* at 2:45-65. And the '347 patent explains that “[t]he system and methods described herein are referred to as “user-focusing.” 3:43-46.

50. I have been informed by counsel that a patent specification may limit the scope of the claims by making it clear that the invention does not include a particular feature. In my opinion, that is precisely what this section of the '347 patent specification has done. Specifically, a POSITA would understand the '347 patent to be stating that “predistortion” does not include “precoding techniques” that use “simplified representations of [the] channel” like a “codebook.” '347, 11:59-67. Moreover, that statement applies to all the “systems and methods described” in the '347 patent specification, further confirming that “predistortion”—at least as that term is used by the '347 patent—explicitly excludes precoding using a codebook.

51. Thus, based on my review of the '347 patent intrinsic evidence, it is my opinion that the term “predistorted” should be construed to mean “distorted before

transmission, not including precoding using a codebook.” By comparison, the “plain and ordinary” construction proposed by Cobblestone focus on the wrong timeframe (after instead of before transmission) and fails to account for the clear statements in the ’347 patent specification excluding precoding techniques that use codebooks, and would improperly expand the scope of the claims in a manner inconsistent with the ’347 patent specification.

**2. “path parameter information” (claims 19–22)**

<b>Term</b>	<b>Cobblestone’s Proposed Construction</b>	<b>Apple’s Proposed Construction</b>
“path parameter information” (claims 19–22)	Plain and ordinary meaning	“estimated parameters of the propagation path, excluding simplified channel status information such as codebook information”

52. I understand that the parties dispute the scope of the term “path parameter information.” In particular, my understanding is that the primary dispute is whether the ’347 specification excludes “simplified channel status information such as codebook information” from the meaning of “path parameter information.” As explained below, in my opinion Apple is correct that the term “path parameter information” does not include simplified channel status information such as codebook information. Rather, the intrinsic record supports Apple’s construction that the term “path parameter information” refers to “estimated parameters of the propagation path, excluding simplified channel status information such as codebook information.”

53. The term “path propagation information” is not a term of art, and does not have an established and well understood meaning outside the context of the ’347 patent. Apart from the disclaimers in the ’347 patent specification explicitly excluding certain

subject matter from the scope of the claims, a POSITA would have understood that the term “path propagation information” as used in the ’347 patent refers to the estimated parameters of a propagation path. This is consistent with both the surrounding language in claim 19 and the ’347 patent specification.

54. Claim 19 recites “performing a channel estimation based on the first signal to obtain path parameter information of the first propagation path.” ’347, claim 19. From this language, path propagation information must be (1) based on an estimation and (2) specific to a propagation path.

55. That understanding is also consistent with the ’347 patent specification as a whole. As discussed above in Section VIII.B (Technical Background of the ’347 Patent), the approach described by the ’347 includes the step of transmitting a first signal from the receiver to the transmitter, and then performing a “channel estimation of a first signal is performed so as to obtain path parameter information of the propagation path,” such as *“estimates of the delay  $\tau$ , the Doppler frequency  $u$ , direction of arrival  $\Omega_1$ , direction of departure  $\Omega_2$ , and complex amplitude  $a$  for each of the propagation paths.”* ’347, 8:4-16. The Doppler frequency, directions of arrival and departure and the complex amplitude are parameters, and thus, this statement refers to “estimates of [parameters] of the propagation paths.” The receiver then feeds backs the path parameter information to the transmitter, which will use that path parameter information to “pre-distort[] the transmitted signals in such a way that the channel’s effect is automatically equalized during the propagation.” ’347, 11:3-12. Accordingly, “path propagation information” refers to the “estimated parameters of the propagation path.”

56. Like the term “predistorted” that I discussed above in Section VIII.C.1, the ’347 patent also goes further to explain how “path parameter information” differs from the types of channel information used in conventional techniques. In the same way that the ’347 patent makes it clear that the term “predistorted” does not include precoding techniques, the ’347 patent also makes it clear that “path parameter information” does not include simplified representations of the channel (e.g., such as those defined in terms of codebooks). ’347 patent, 11:59-67. The ’347 patent also goes further by distinguishing and noting deficiencies of the use of codebooks in particular, noting that the “full-dimensional parametric description of the channel”—referring to path parameter information—“can be much more accurate than using the codebooks”:

B. Comparison to Precoding Techniques

The systems and methods described herein can make use of the concept of “pre-distortion,” which has significant difference from the conventional precoding techniques. *The latter can make use of simplified representations of [the] channel, e.g. in terms of code-book, while the system and methods described above make use of the parameters of the propagation channel, e.g. the delay, Doppler frequencies, directions of departure and directions of arrival. This full-dimensional parametric description of the channel can be much more accurate than using the codebooks.*

’347 patent, 11:59-67. Based on this clear statement, a POSITA would have understood that all the “systems and methods” of the ’347 patent make use of path parameter information in the form of the actual “parameters of the propagation channel.” By comparison a POSITA would have understood that using “simplified representations of [the] channel,” such as representing the channel in terms of a codebook, are part of conventional precoding techniques and fall squarely outside the scope of the purported invention.

57. Elsewhere in the specification, the '347 patent also states that “the systems and methods described herein make use of the parameters of propagation [i.e., path parameter information] *instead of the simplified channel status information.*” '347, 14:18-24. A POSITA would have understood that the term “simplified channel status information” is the same as the “simplified representations of the channel” referenced earlier in the '347 patent, and would also include codebook information. *Compare* '347 patent, 11:59-67 *with* '347, 14:18-24. Indeed, “channel status information” is itself a “representation[] of the channel.” Accordingly, a POSITA would have understood this additional disclaimer—explicitly excluding the use of “simplified channel status information” from the “systems and methods” of the '347 patent—to further confirm that “path parameter information” excludes simplified channel status information such as codebook information. *See* '347 patent, 11:59-67, 14:18-24.

58. Thus, based on my review of the '347 patent intrinsic evidence, it is my opinion that the term “path parameter information” should be construed to mean “estimated parameters of the propagation path, excluding simplified channel status information such as codebook information.” By comparison, the “plain and ordinary” construction proposed by Cobblestone fails to account for the clear statements in the '347 patent specification excluding simplified channel status information (e.g., such as codebook information), and would improperly expand the scope of the claims in a manner inconsistent with the '347 patent specification.

I declare under penalty of perjury that the foregoing is true and correct.

Dated: May 9, 2025 in Notre Dame, IN

A handwritten signature in black ink, appearing to read "Bertrand Hochwald", written in a cursive style.

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Dr. Bertrand Hochwald, Ph.D.

# APPENDIX A

**Bertrand M. Hochwald**

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South Bend, IN 46617  
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**Degrees:**

BS (Engineering) 1984, Swarthmore College  
MS (Electrical Engineering) 1986, Duke University  
MA (Statistics) 1993, Yale University  
PhD (Electrical Engineering) 1995, Yale University

**Experience:**

Department of Defense, Fort Meade, Maryland. *Electrical Engineer*, 1986–1989.  
Yale University, New Haven, Connecticut. *Teaching assistant*, 1990–1994.  
University of Illinois, Urbana-Champaign  
*Postdoctoral Research Associate in data compression*, 1995.  
*Visiting Faculty in Department of Electrical Engineering*, 1996.  
Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey  
*Member of Technical Staff*, 1996–2002.  
*Distinguished Member of Technical Staff*, 2002–2005.  
Columbia University, New York  
*Visiting Faculty in Department of Electrical Engineering*, 2005.  
Beceem Communications, Santa Clara, California  
*Chief Scientist*, 2005–2009,  
*Vice-President Systems Engineering*, 2009–2010.  
Stanford University, Palo Alto, California  
*Consulting Professor of Electrical Engineering*, 2006–2010.  
University of Notre Dame, Notre Dame, Indiana  
*Frank M. Freimann Professor of Electrical Engineering*, 2011–present.  
University of Notre Dame, Notre Dame, Indiana  
*Co-Director of The Wireless Institute*, 2016–present.

**Honors:**

New York State: *Regents Scholarship*, 1980.  
Pennsylvania ACM computer programming competition: *Winner*, 1983.  
Duke University: *Eta Kappa Nu engineering honor society*, 1985.  
Department of Defense: *Special Achievement Awards*, 1988, 1989.  
Yale University: *Prize Teaching Fellowship teaching award*, 1993.  
Bell Laboratories: *President's Gold Award*, 2002.  
Thomson Essential Science Indicators  
*Top one-tenth of one percent referenced papers*, 2002 and 2003.  
IEEE Transactions on Communications  
*Stephen O. Rice Best Paper Award*, 2006.  
IEEE  
*Fellow*, 2008.  
Thomson Reuters  
*World's Most Influential Scientific Minds*, multiple years.

**Honors (cont'd):**

IEEE Transactions on Circuits and Systems  
*Young Author Best Paper Award*, 2016 (my PhD student).  
 IEEE Transactions on Antennas and Propagation  
*H. A. Wheeler Prize Paper Award*, 2018.  
 The Marconi Society  
*Paul Baran Young Scholar Award*, 2018 (my PhD student).  
 National Academy of Inventors  
*Fellow*, 2019.

**Research Gifts, Grants and Contracts:**

Principal Investigator, “NSF EAGER: Multiple Transmitter Chains to Minimize Exposure to Electromagnetic Radiation in Portable Devices,” National Science Foundation CCF-1141868, August 1, 2011–July 31, 2013, \$200,000.  
 Co-Principal Investigator, “Planning Grant: I/UCRC in Broadband Wireless Technologies and Applications,” National Science Foundation IIP-1266124, April 1, 2013–March 31, 2014, \$14,544.  
 Co-Principal Investigator, “I/UCRC Phase I: BWAC@NDWI: Broadband Wireless Access and Applications at the Notre Dame Wireless Institute,” National Science Foundation, IIP-1439682, August 1, 2014–July 31, 2019, \$325,000.  
 Principal Investigator, “Modeling, Analysis, and Code Design for Portable Wireless Transmitters Subject to an Electromagnetic Exposure Constraint,” National Science Foundation, CCF-1403458, September 1, 2014–August 31, 2018, \$1,200,000.  
 Principal Investigator, “Notre Dame Millimeter-Band Capability,” Equipment Restoration and Renewal Grant, May 31, 2015–May 31, 2016, \$183,000.  
 Principal Investigator, “Channel Estimation Technologies based on AoA/AoD in High-Frequency Wireless Communication Systems,” Huawei Technologies, June 22, 2015–October 31, 2016, \$181,217.  
 Principal Investigator, “*Radiohound*: A Low-Cost Spectrum Beacon/Sensor with Millimeter Wave Capability,” Alcatel-Lucent and Interdigital Corporations, June 1, 2015–May 31, 2018, \$240,000.  
 Principal Investigator, “Low-Complexity High-Bandwidth Multiport Matching Networks for Coupled Loads,” National Science Foundation, ECCS-1509188, August 1, 2015–July 31, 2018, \$400,000.  
 Principal Investigator, “Notre Dame Coherent RadioHound: A Distributed Spectrum Sensor Network,” Laboratory for Telecommunications Sciences, May 6, 2016–May 5, 2017, \$187,124.  
 Co-Principal Investigator, “Wideband Time-Domain Millimeter-Wave Device and Channel Characterization Testbed,” Department of the Navy, July 15, 2016–July 14, 2017, \$326,573.  
 Principal Investigator, “SpecEES: Wideband Wireless Communications with Low-Power Transceiver-Cell Circuits,” National Science Foundation, ECCS-1731056, August 15, 2017–August 14, 2020, \$650,000.  
 Principal Investigator, “Data Gathering Plan for Radio-Frequency Machine-Learning Systems,” Defense Advanced Research Projects Agency, October 1, 2017–June 1, 2018, \$149,332.  
 Principal Investigator, “REU Site: AWaRE Advanced Wireless Research Experiences at the University of Notre Dame,” National Science Foundation CNS-1757804, January 15, 2018–December 31, 2020, \$359,789.  
 Co-Principal Investigator, “Physical Layer Signature Discrimination of Transmitters,” The George J Kostas Research Institute for Homeland Security at Northeastern University (KRI), March 30, 2018–October 29, 2020, \$100,000.

**Research Gifts, Grants and Contracts (cont'd):**

- Co-Principal Investigator, "An Infrastructure-less and Heterogeneous Distributed Sensor for Electromagnetic Spectrum Sensing and Emitter Geolocation," Department of the Army, June 15, 2018–June 14, 2019, \$370,234.
- Co-Principal Investigator, "Improving STEM Retention Through Hands-On Implementation and Red-Teaming," Office of Naval Research, August 15, 2018–August 14, 2021, \$735,830.
- Principal Investigator, "Ultra Low Cost/Power Massive MIMO Architecture and Algorithm," Futurewei Technologies, Inc, Gift, September 13, 2018, \$200,000.
- Principal Investigator, "Ultra Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, September 15, 2018–September 14, 2020, \$220,000.
- Principal Investigator, "MLWiNS: Quality Versus Quantity in Spectrum Sensing with Distributed Sensors," National Science Foundation jointly with Intel Corporation, July 1, 2020–June 30, 2023, \$665,000.
- Principal Investigator, "Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, January 1, 2021–December 31, 2021, \$110,000.
- Co-Principal Investigator, "Stationary and Aerial-Based RF/Radar Detection of Drones, Concealed Threats and Anomalous Communications," Department of Homeland Security, October 1, 2021–September 30, 2031, \$1,000,000.
- Senior Personnel, "SpectrumX - An NSF Spectrum Innovation Center," National Science Foundation, September 15, 2021–September 14, 2026, \$25,000,000.
- Co-Principal Investigator, "Self-Powered Wireless Sensor System for Health Monitoring of Liquid-Sodium Cooled Fast Reactors," Department of Energy, October 1, 2021–September 30, 2024, \$640,000.
- Principal Investigator, "Upper Midband Software-Defined Radio Workshop," supplement to "SII-Center: SpectrumX–An NSF Spectrum Innovation Center," September 15, 2021–August 31, 2026, \$110,278.
- Principal Investigator, "Ultra Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, January 1, 2022–December 31, 2022, \$110,000.
- Principal Investigator, "Ultra Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, January 1, 2023–December 31, 2023, \$110,000.
- Co-Principal Investigator, "VSF.1 Virtual SENTRY Framework Development," Department of Homeland Security, July 1, 2023–June 30, 2024, \$328,500.
- Principal Investigator, "cmWave (Upper-Midband) Spectrum Usage and Prospects for International Mobile Telecommunications (IMT)," AT&T Innovation Lab, January 1, 2024–December 31, 2024, \$75,000.
- Co-Principal Investigator, "VSF.1 Virtual SENTRY Framework Development," Department of Homeland Security, July 1, 2024–June 30, 2025, \$274,565.
- Co-Principal Investigator, "Collaborative Research: CIRC: GRAND: Houdini: Design and Development of a Open-Access Very Diverse Spectrum Platform for Wireless Networking, Imaging and Sensing," National Science Foundation, June 1, 2024–May 31, 2029, \$438,701.

**Patents:**

- “Multiple Antenna Communication System and Method Thereof,” #6058105, May 2, 2000.
- “Wireless Transmission Method for Antenna Arrays, Having Improved Resistance to Fading,” #6327310, December 4, 2001.
- “Antenna Array Having Reduced Sensitivity to Frequency-Shift Effects,” #6349219, February 19, 2002.
- “Wireless Transmission Method for Antenna Arrays Using Unitary Space-Time Signals,” #6363121, March 26, 2002.
- “Space-Time Spreading Method of CDMA Wireless Communication,” #6452916, September 17, 2002.
- “Method of Wireless Communication Using Structured Unitary Space-Time Signal Constellations,” #6693976, February 17, 2004.
- “Method for Wireless Differential Communication Using Multiple Transmitter Antennas,” #6724842, April 20, 2004.
- “Method for Wireless Communication using Unitary Space-Time Signal Constellations,” #6801579, October 5, 2004.
- “Method of Multiple-Antenna Wireless Communication Using Space-Time Codes,” #6944236, September 13, 2005.
- “Cayley-Encoding of Unitary Matrices for Differential Communication,” #7170954, January 30, 2007.
- “Method and Apparatus for Detection and Decoding of Signals Received from a Linear Propagation Channel,” #7236536, June 26, 2007.
- “Method of Signal Transmission to Multiple Users From a Multi-Element Array,” #7317764, January 08, 2008.
- “Downlink Coordinated Transmission in OFDMA Systems,” #7706335, April 27, 2010.
- “Downlink Coordinated Transmission in OFDMA Systems, Including WiMax Systems,” #7764658, July 27, 2010.
- “Spherical Decoder for Wireless Communications,” #7822150, October 26, 2010.
- “Method for Estimating Frequency Offset at a Subscriber Station Receiver in a Multi-Carrier System,” #7916800, March 29, 2011.
- “Estimating Frequency Offset at a Subscriber Station Receiver,” #7929595, April 19, 2011.
- “Method of a Receiver Estimating a Plurality of Channels,” #8194774, June 5, 2012.
- “Method of Aiding Uplink Beamforming Transmission,” #8259672, September 4, 2012.
- “Multi-Stream Priority-Based Space-Time Coding,” #8284693, October 9, 2012.
- “Estimating a Subscriber Location,” #8290508, October 16, 2012.
- “Selecting a Transmission Mode Between a Subscriber and a Base Station,” #8311003, November 13, 2012.
- “Noninvasive Characterization of Electrical Power Distribution Systems,” #8427169, April 23, 2013.
- “Method and System of Beamforming a Broadband Signal Through a Multiport Network,” #8432997, April 30, 2013.
- “Estimating a Subscriber Location,” #8611925, December 17, 2013.
- “Characterization of Electrical Power Distribution Systems,” #8633705, January 21, 2014.
- “Allocating Antennas for Cyclic Delay Diversity,” #8675761, March 18, 2014.
- “Wireless Transceivers with Filter Arrangement for WiFi and WiMax coexistence,” #8681748, March 25, 2014.
- “Multiple Antenna Signal Transmission,” #8737529, May 27, 2014.
- “Selecting a Transmission Mode Between a Subscriber and a Base Station,” #8750236, June 10, 2014.
- “Multiple Antenna Transceiver,” #8761694, June 24, 2014.

**Patents (cont'd):**

- “Characterization of Electrical Power Distribution Systems Using Characterization Matrices,” #8810253, August 19, 2014.
- “Method and System of Beamforming a Broadband Signal Through a Multiport Network,” #8811530, August 19, 2014.
- “Distribution of Transmit Signal to Multiple Transmit Antennas for Reduction, of Measured Specific Absorption Rate,” #8811918, August 19, 2014.
- “Method of Transmission from Multiple Transmit Chains Based on a Cost Function” for Electromagnetic Radiation,” #8818294, August 26, 2014.
- “Method and System for Uplink Coordinated Reception in Orthogonal Frequency Division Multiple Access Systems,” #8855046, October 7, 2014.
- “Method of Coding Using Multiple Transmit Chains for Reduced Exposure to Electromagnetic Radiation,” #8929828, January 6, 2015.
- “Method and Apparatus for Link Adaptation in a Wireless Communication Network,” #8942184, January 27, 2015.
- “Method and Apparatus for Managing Uplink Communication in Wireless Network,” #9026123, May 5, 2015.
- “Method of Updating Transmission of Channel Information Based on Eaves-Dropping of Beamformed Signals,” #9178597, December 8, 2015.
- “Adaptive Transmit Beamforming,” #9209876, December 8, 2015.
- “Method and Apparatus for Managing Uplink Communication in a Wireless Communication Network,” #9210716, December 8, 2015.
- “Wireless Transceivers with Filter Arrangement for WiFi and LTE coexistence,” #9232564, January 5, 2016.
- “Mobile Subscriber Information Transmission Over Multiple Uplink Frames,” #9236975, January 12, 2016.
- “Method of Aiding Uplink Beamforming Transmission,” #9344178, May 17, 2016.
- “Adaptive Transmit Beamforming for Frequency Division Duplexing Systems,” #9537684, January 3, 2017.
- “Mitigating Beam Squint in Millimeter Wave Wireless Communication Systems,” #10819405, October 27, 2020.
- “Low-Resolution, Low-Power, Radio-Frequency Receiver,” #11121896, September 14, 2021.
- “Local Oscillator Synchronization for Coherent Phase-Array System, #11239877, February 1, 2022.
- “Ultra-Low-Power Millimeter-Wave to Baseband Receiver Module for Scalable Massive MIMO,” #11296742, April 5, 2022.
- “Low-Power, Self-Referenced Receiver,” #11303347, April 12, 2022.
- “Low-Resolution, Low-Power, Radio Frequency Receiver,” #11483190, October 25, 2022.
- “Ultra-Low-Power Millimeter-Wave to Baseband Receiver Module for Scalable Massive MIMO,” #11664840, May 30, 2023.
- “Methods and Apparatus for Determining Electromagnetic Exposure Compliance of Multi-antenna Devices,” #11940477, March 3, 2024.

### **Professional Feature Videos, Projects, Web-pages, and Plenary Talks**

“Multiple Antennas: How a Point-to-Point Advantage Becomes a Multi-user Advantage.” Plenary Speaker at the *22nd Biennial Symposium on Communications*, Queens University, Kingston, Ontario, June 2004.

“A Random-Channel Graph-Theoretic Perspective of Wireless Networks.” Plenary Speaker at the *2006 Seventh Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Cannes, France, July 2006.

“The Role of MIMO in Fourth-Generation Mobile Wireless Systems and Beyond.” Plenary Speaker at the *2009 IEEE Communication Theory Workshop*, Napa, California, May 2009.

“What Have We Learned So Far About MIMO in Mobile Wireless Systems?” Plenary Speaker at the *2009 Tenth Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Perugia, Italy, June 2009.

“Bandwidth of Large-Scale Multiport Radio-Frequency Systems.” Plenary Speaker at the *20th International ITG Workshop on Smart Antennas*, Munich, Germany, March 2016.

“Building a Better Phone,” University of Notre Dame web page feature story, 2016:  
<https://www.nd.edu/stories/building-a-better-phone/>

“Notre Dame Researchers Target Cell Phone Radiation,” WSBT television feature story, 2016:  
<https://wsbt.com/news/local/notre-dame-researchers-target-cell-phone-radiation>.  
<https://engineering.nd.edu/news-publications/engineering-in-the-news/notre-dame-researchers-target-cell-phone-radiation>

Principle Investigator for the *RadioHound Spectrum Sensing System*, 2015–present:  
<https://wireless.nd.edu/research/radiohound-distributed-spectrum-sensing>

“Communication Theory and Circuit Design,” Plenary Speaker at 2024 Information Theory and Applications Workshop, San Diego, CA, February 2024.

## Editorial, Panelist, and Professional Service Activities

Owner and Editor of <http://mars.bell-labs.com>, the *Multiple-Antenna Research and Solutions* web-site dedicated to promoting research into space-time techniques, 1998–2005. (800 subscribers)

Guest Associate Editor, *IEEE Transactions on Signal Processing Special Issue on Signal Processing for Communications*, with N. Al-Dhahir, G. Giannakis, B. Hughes and T. Marzetta, vol. 50, October 2002.

Guest Editor, *IEEE Transactions on Information Theory Special Issue on Space-Time Transmission, Reception, Coding and Signal Design*, with G. Caire, B. Hassibi and T. Marzetta, vol. 49, October 2003.

Associate Editor for MIMO Techniques, *IEEE Transactions on Communications*, November 2003–2005.

Associate Editor for *IEEE Transactions on Information Theory*, 2011–2012.

IEEE Fellows Committee for the Information Theory Society, 2016–2017.

Panelist, National Science Foundation Signal Processing Systems Faculty Early Career Development Program (CAREER), November 2002; Computer and Information Science Communications/Signal-Processing Research Program, April 2004; Theoretical Foundations of Communications and Signal-Processing Research Program, May 2007; Computing and Communication Foundations (CCF): Core Programs, February 2010; Communications and Information Foundations (CIF), December 2011; Communications and Signal Processing, April 2014; Computer and Network Systems Research Experience for Undergraduates (CNS-REU), November 2018. Technical Program Chair, *2018 IEEE Communication Theory Workshop*, Miramar Beach, Florida, May 2018.

## University Service Activities

Graduate Admissions Committee, 2012–2024.

Graduate Committee, 2012–2013, 2016–2018.

College Council, 2014–2017.

Committee for Appointments and Promotions, 2016–2017.

CRADA (Cooperative Research and Development Agreement) between University of Notre Dame and Crane Naval Base, Crane, Indiana, 2016–present.

Co-Director, University of Notre Dame Wireless Institute, 2016–present. In 2017–2018, approximately \$4M/yr in expenditures was routed through the Institute in various projects, including *RadioHound*.

Principal Investigator, National Science Foundation-funded Research Experience for Undergraduates (REU), sponsoring ten undergraduates from around the United States that visit the University of Notre Dame Wireless Institute for a ten-week research program every summer, 2018–2022

**Past Co-Advised PhD Students:**

Ibrahim Abou-Faycal (Massachusetts Institute of Technology), 1998  
Sriram Vishwanath (Stanford University), 2002  
Christian Peel (Brigham-Young University), 2003  
Radhika Gowaikar (Caltech), 2005  
Heunchul Lee and Kyoung Jae Lee (Korea University), 2007

**MS and PhD Students at University of Notre Dame:**

Luyu Zhao, MS 2013  
Ding Nie, PhD 2015  
Kang Gao, PhD 2020  
Arash EbadiShahrivar, PhD 2021  
Abbas Termos, PhD 2022  
Mir Sahariyat, MS 2022  
Xiangbo Meng, PhD 2024  
Christopher Wahl, PhD  
Nazim Bicer, PhD  
Yuxi Chen, PhD  
Zhiyu Shen, PhD

**Courses, Book Chapters, Tutorials**

“Probabilistic Methods in Signal and System Analysis.” Senior-level undergraduate course, University of Illinois, Urbana-Champaign, January–May 1996.

“Multi-Antenna Wireless Communications—from Theory to Algorithms,” with B. Hassibi and T. Marzetta. Tutorial at *IEEE Conference on Acoustics, Speech and Signal Processing*, Orlando, FL, May 2002.

“Communication Theory.” Senior-level undergraduate course, Columbia University, September–December 2005.

“Linear and Dirty-Paper Techniques for the Multiuser MIMO Downlink,” with Christian B. Peel, Quentin H. Spencer, A. Lee Swindlehurst and Martin Haardt. Book chapter in *Space-Time Processing for MIMO Communications*, A. B. Gershman and N. D. Sidiropoulos (editors), Chichester: John Wiley & Sons, 2005.

## Theses and Journal Papers

- “Aspects of Vector-Sensor Processing.” PhD thesis, Yale University, 1995.
- B. Hochwald and A. Nehorai, “Concentrated Cramér-Rao bound expressions,” *IEEE Transactions on Information Theory*, vol. 40, pp. 363–371, March 1994.
- B. Hochwald and A. Nehorai, “Minimum bias priors for estimating additive terms in state-space models,” *IEEE Transactions on Automatic Control*, vol. 40, pp. 684–693, April 1995.
- B. Hochwald and A. Nehorai, “Polarimetric modeling and parameter estimation with applications to remote sensing,” *IEEE Transactions on Signal Processing*, vol. 43, pp. 1923–1935, August 1995.
- B. Hochwald and A. Nehorai, “Identifiability in array processing models with vector-sensor applications,” *IEEE Transactions on Signal Processing*, vol. 44, pp. 83–95, January 1996.
- B. Hochwald and A. Nehorai, “On identifiability and information-regularity in parameterized normal distributions,” *Circuits, Systems, and Signal Processing*, vol. 16, pp. 83–89, January 1997.
- B. Hochwald and A. Nehorai, “Magnetoencephalography with diversely-oriented and multi-component sensors,” *IEEE Transactions on Biomedical Engineering*, vol. 44, pp. 40–50, January 1997.
- B. Hochwald and K. Zeger, “Tradeoff between source and channel coding,” *IEEE Transactions on Information Theory*, vol. 43, pp. 1412–1424, September 1997.
- B. Hochwald, “Tradeoff between source and channel coding on a Gaussian channel,” *IEEE Transactions on Information Theory*, vol. 44, pp. 3044–3055, November 1998.
- B. Hochwald and P. Jelenković, “State Learning and Mixing in Entropy of Hidden Markov Processes and the Gilbert-Elliott Channel,” *IEEE Transactions on Information Theory*, vol. 45, pp. 128–138, January 1999.
- T. Marzetta and B. Hochwald, “Capacity of a mobile multiple-antenna communication link in Rayleigh flat fading,” *IEEE Transactions on Information Theory*, vol. 45, pp. 139–157, January 1999.
- B. Hochwald and T. Marzetta, “Unitary space-time modulation for multiple-antenna communications in Rayleigh flat fading,” *IEEE Transactions on Information Theory*, vol. 46, pp. 543–564, March 2000.
- B. Hochwald, T. Marzetta, T. Richardson, W. Sweldens, and R. Urbanke, “Systematic design of unitary space-time constellations,” *IEEE Transactions on Information Theory*, vol. 46, pp. 1962–1973, September 2000.
- B. Hochwald and W. Sweldens, “Differential unitary space-time modulation,” *IEEE Transactions on Communications*, vol. 48, pp. 2041–2052, December 2000.
- B. Hochwald and T. Marzetta, “Adapting a downlink array from uplink measurements,” *IEEE Transactions on Signal Processing*, vol. 49, pp. 642–653, March 2001.
- B. Hochwald, T. Marzetta, and C. Papadias, “A transmitter diversity scheme for wideband CDMA systems based on space-time spreading,” *IEEE Journal on Selected Areas of Communication: Special Issue on Wideband CDMA*, vol. 19, pp. 48–60, March 2001.
- A. Shokrollahi, B. Hassibi, B. Hochwald, and W. Sweldens, “Representation theory for high-rate multiple-antenna code design,” *IEEE Transactions on Information Theory*, vol. 47, pp. 2335–2367, September 2001.

**Journal Papers (cont'd)**

- B. Hochwald, T. Marzetta, and B. Hassibi, "Space-time autocoding," *IEEE Transactions on Information Theory*, vol. 47, pp. 2761–2781, November 2001.
- T. Marzetta, B. Hassibi, and B. Hochwald, "Structured unitary space-time autocoding constellations," *IEEE Transactions on Information Theory*, vol. 48, pp. 942–950, April 2002.
- B. Hassibi and B. Hochwald, "Cayley differential unitary space-time codes," *IEEE Transactions on Information Theory*, vol. 48, pp. 1485–1503, June 2002.
- B. Hassibi and B. Hochwald, "High-rate codes that are linear in space and time," *IEEE Transactions on Information Theory*, vol. 48, pp. 1804–1824, July 2002.
- N. Al-Dhahir, G. Giannakis, B. Hochwald, B. Hughes, and T. Marzetta, "Guest editorial," *IEEE Transactions on Signal Processing*, vol. 50, pp. 2381–2384, October 2002.
- B. Hochwald and S. ten Brink, "Achieving near-capacity on a multiple-antenna channel," *IEEE Transactions on Communications*, vol. 53, pp. 389–399, March 2003.
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